



SWR

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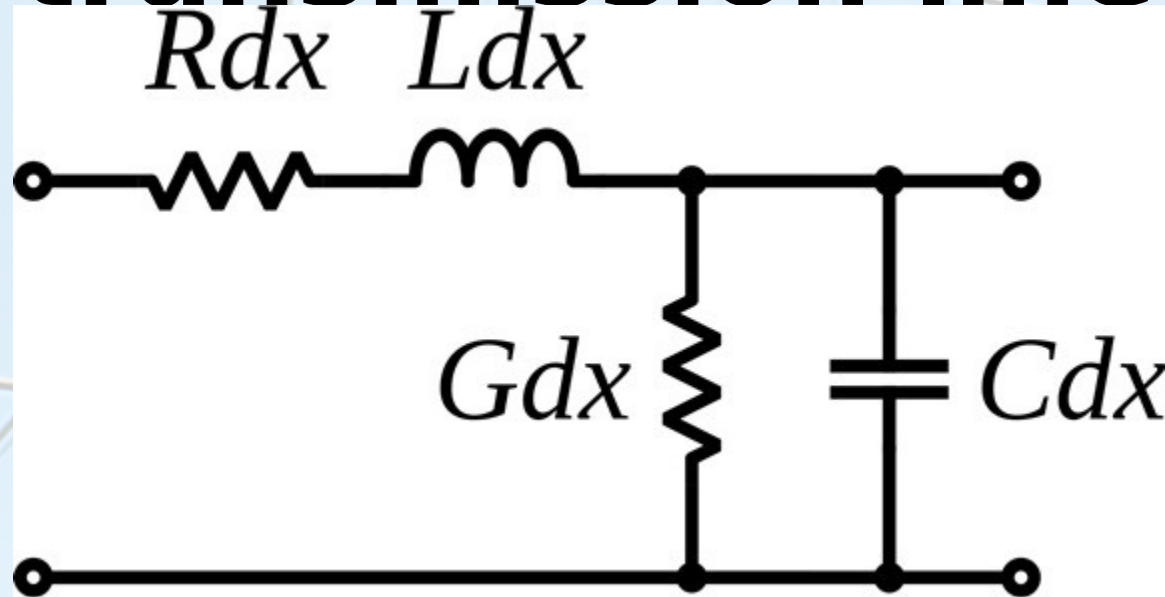
Transmission line

Carries the signal from the transceiver to the antenna and back

Today we depend heavily on coaxial cable for amateur radio transmission lines

Coax has a characteristic impedance, which doesn't vary (much) with frequency, within most amateur bands of interest,

Coaxial cable transmission line



Characteristic impedance (Z_0) of coax arises from its per-length resistance, inductance, conductance, and capacitance

The impedance of coax

Coax impedance is calculated from this network (the **s** is simply $j\omega$, which equates to ω for

$$Z = \sqrt{\frac{R + sL}{G + sC}}$$

Typically, **G** (the inverse of resistance between the conductors) and **R** are very small

$$Z_0 = \sqrt{\frac{sL}{sC}} = \sqrt{\frac{L}{C}}$$

Why its impedance is 50 ohms

On an analyzer, RG-8X coax (for example) measures about 0.077 $\mu\text{H}/\text{ft}$. The charts show that RG-8X exhibits about 30.8 pF/ft, so

$$\mathbf{Z_0 = \sqrt{[(0.077 \mu\text{H}/\text{ft}) / (30.8 \text{ pF}/\text{ft})]} \approx 50 \text{ ohms}}$$

regardless of frequency...to a point

In an ideal world

The impedance of the transmission line matches that of the source (transceiver)

The impedance of the load (antenna) matches that of the transmission line and transceiver

This allows for maximum power transfer; that is, *the most power you can transfer from your transceiver to the antenna occurs when all three impedances are the same*

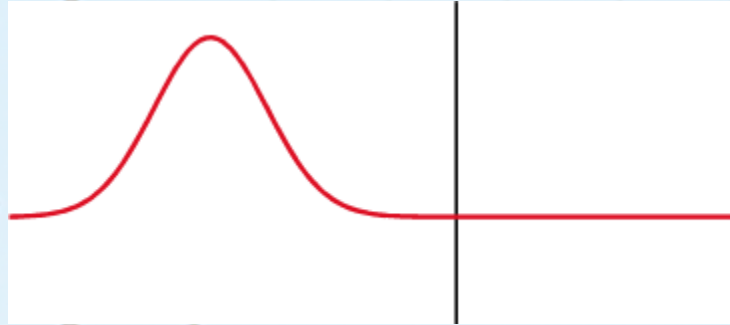
In the real world

The impedance of the transmission line matches that of the source (transceiver)

The impedance of the load (antenna) ***does not perfectly match*** that of the transmission line or transceiver

When a signal encounters the antenna impedance that does not perfectly match that of the transmission line, ***part of the signal is reflected back to the transceiver***

Reflection



Signal reflection is measured by the ***reflection coefficient (Γ)***, which is the reflected voltage compared to the forward (sent) voltage

$$\Gamma = \frac{V_r}{V_f}$$

Magnitudes

All the voltage, current, and impedance quantities are complex numbers

$$Z = X + jy$$

But in examining standing waves, we're only interested in the worst cases (*magnitudes*), but also taking into account the phase angles (maximum case = in-phase, and minimum case = out-of-phase) separately

$$|z| = \sqrt{x^2 + y^2}$$

Voltage superposition

The two voltages add where they are in phase, and subtract where they are not

$$|V_{\max}| = |V_f| + |V_r|$$

$$|V_{\min}| = |V_f| - |V_r|$$

Then substituting for the reflection coefficient

$$\begin{aligned} &= |V_f| + |\Gamma V_f| \\ &= (1 + |\Gamma|)|V_f| \end{aligned}$$

$$\begin{aligned} &= |V_f| - |\Gamma V_f| \\ &= (1 - |\Gamma|)|V_f| \end{aligned}$$

Standing wave ratio

SWR, or *standing wave ratio*, is the ratio of maximum and minimum standing wave voltages on the transmission line

$$SWR = \frac{|V_{\max}|}{|V_{\min}|} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

And that derives from the reflection coefficient

SWR approximation

Turns out that SWR can also be approximated by the *ratio of the impedances*:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$\text{SWR} = \frac{|V_{\max}|}{|V_{\min}|} = \frac{1 + |\Gamma|}{1 - |\Gamma|} = \max \left\{ \frac{R_L}{Z_0}, \frac{Z_0}{R_L} \right\}$$

Impedance implication

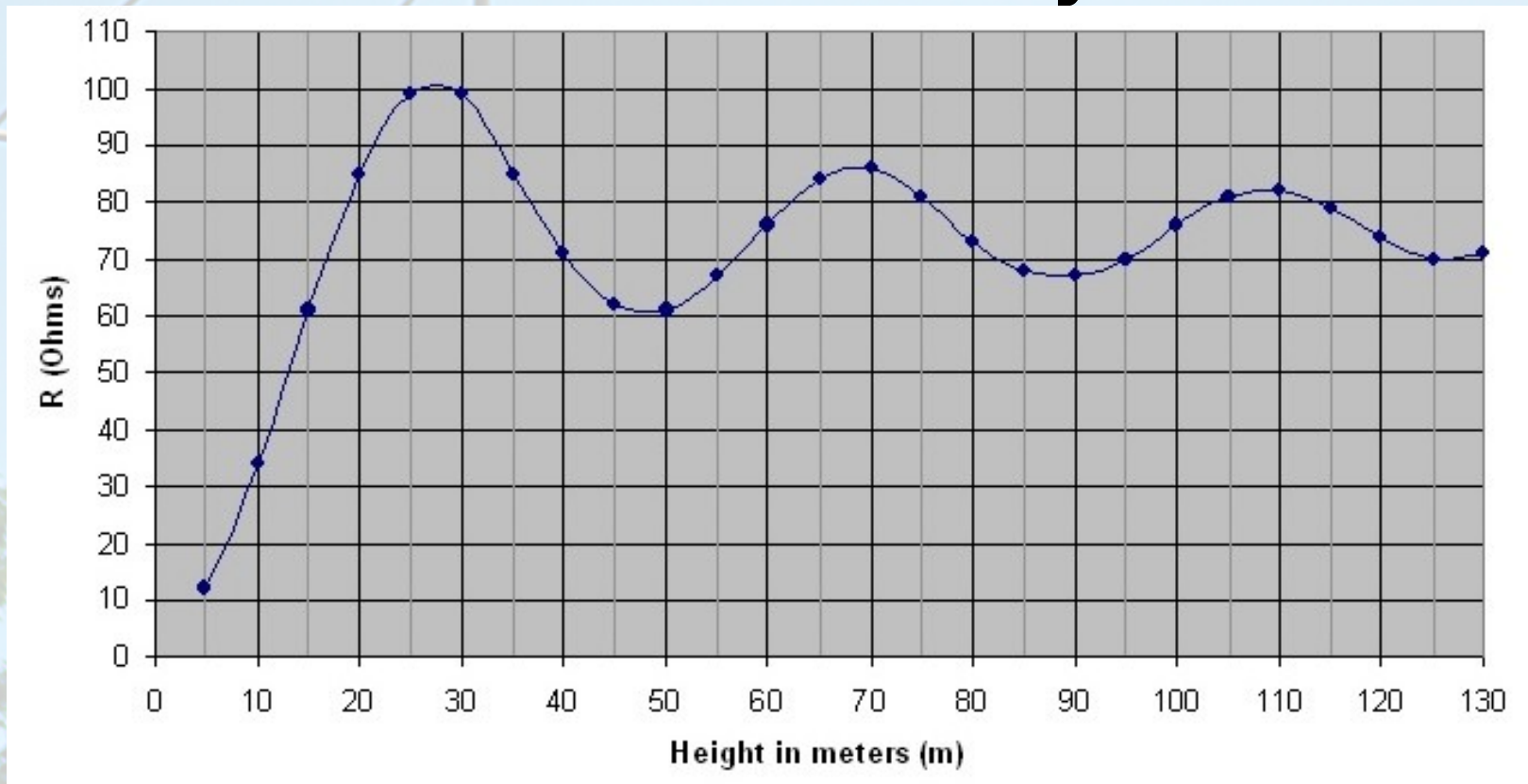
This means you can calculate SWR if you know your antenna system impedance

And you can calculate your antenna system impedance if you know its SWR

For example, a typical half-wave dipole has an impedance of about 73 ohms (this is actually the **radiation resistance, assuming ohmic resistance is small). This means it'll exhibit an SWR of $73 \text{ ohms} \div 50 \text{ ohms} \approx 1.5:1$**

Impedance vs. antenna height

SWR gives you an idea of your antenna's feed point impedance, which can be affected by antenna



Where the reflected signal went

The reflected signal ***returned*** to the transceiver

Because the transceiver output is largely composed of reactive (inductive, capacitive) components, the reflected signal is completely reflected by the transceiver, and is then ***returned*** to the antenna

The entire process repeats until all the signal is radiated from the antenna...with one exception

Transmission line attenuation

Attenuation is the reduction of a quantity, signal power in our case

When a conductor passively performs the attenuation, we often call it ***loss***

All transmission lines have loss because no conductor is perfect

Coaxial cable is especially lossy, in spite of other (inexpensive, non-coupling, simple, etc.) advantages

Signal re-reflection

SWR does not represent loss

**All the re-reflected signal is
returned to the antenna except
that lost in the transmission line**

Open-wire line has almost no loss

**Ladder-line and window-line are
very low-loss**

**Coax is lossy, but very convenient
and inexpensive**

Return loss

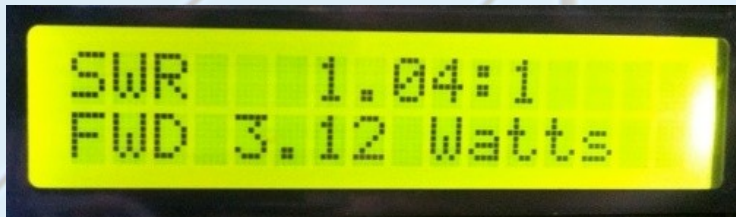
The parameter *return loss* is often used in the RF (radio frequency) and telecommunications industry, and is calculated as

$$RL(\text{dB}) = 10 \log_{10} \frac{P_i}{P_r}$$

But return loss is a partial misnomer, because a) it's based on the notion that reflected power is lost power and b) the lower the SWR, the higher the return loss

SWR meter

You can measure SWR by using the meter built into your rig, or an external meter that displays a number



My preference is the cross-needle meter, which shows the forward power, reflected power, and the SWR where they cross



Too-low of an SWR can kill you

- If your antenna's SWR is below 2.0:1, it'll likely work just fine as-is; if it's below 3.0:1, the internal tuners of most HF rigs will easily perform the matching
- I've seen well-meaning hams climb thin tree branches, trellises, and ladders propped on ladders, to reach out-of-reach antennas in their attempts to adjust them and get their 1.3:1 SWR down to that elusive 1.0:1 reading...or they'll ask me to do it
- *Rest assured that there's no need to risk your life to obtain the unobtainable*
- Living with an SWR of, say, 1.9:1 will work just fine for you, until you change frequency

Who cares?

If all the signal (except a little) goes to the antenna, there are (at least) four reasons people typically want to reduce their antenna system SWR:

- Reduce feed line **loss** (which we've already discussed)
- Prevent transceiver **fold-back**
- Maintain or improve operating **bandwidth**
- Bragging rights

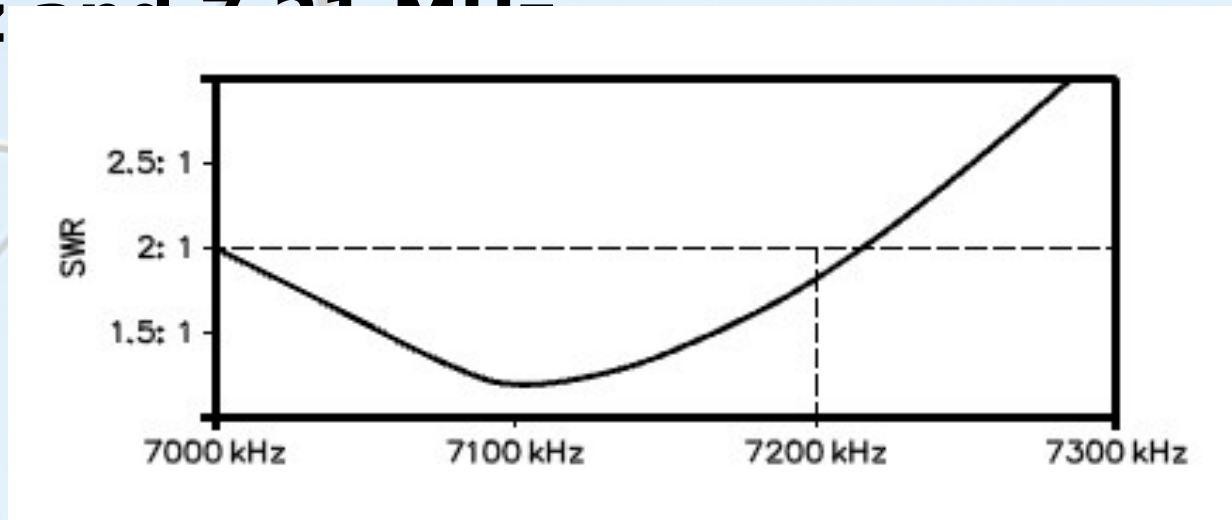
SWR bandwidth

The *SWR bandwidth* of your antenna system is the range of frequencies on which it will present your rig with an SWR of **2.0:1 or lower**

This gives you a pretty good idea what your operating range is, within your band of interest

SWR bandwidth graphically

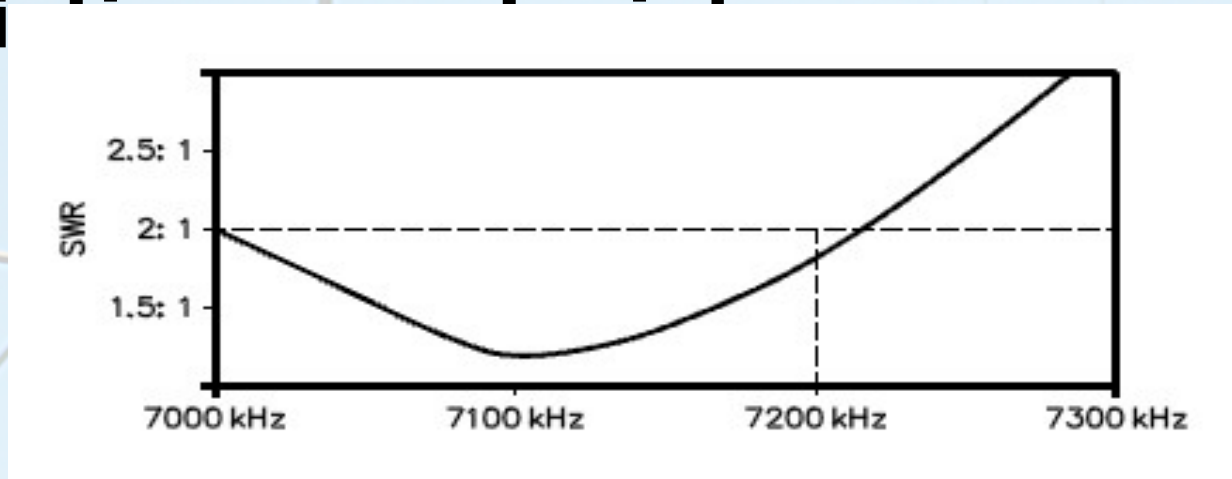
For example, in the following SWR sweep of an antenna system, the range for which it's 2.0:1 or less falls between 7.00 MHz and 7.21 MHz



So, we can say that the antenna system's SWR bandwidth is about 210 kHz, from 7.00 MHz to 7.21 MHz

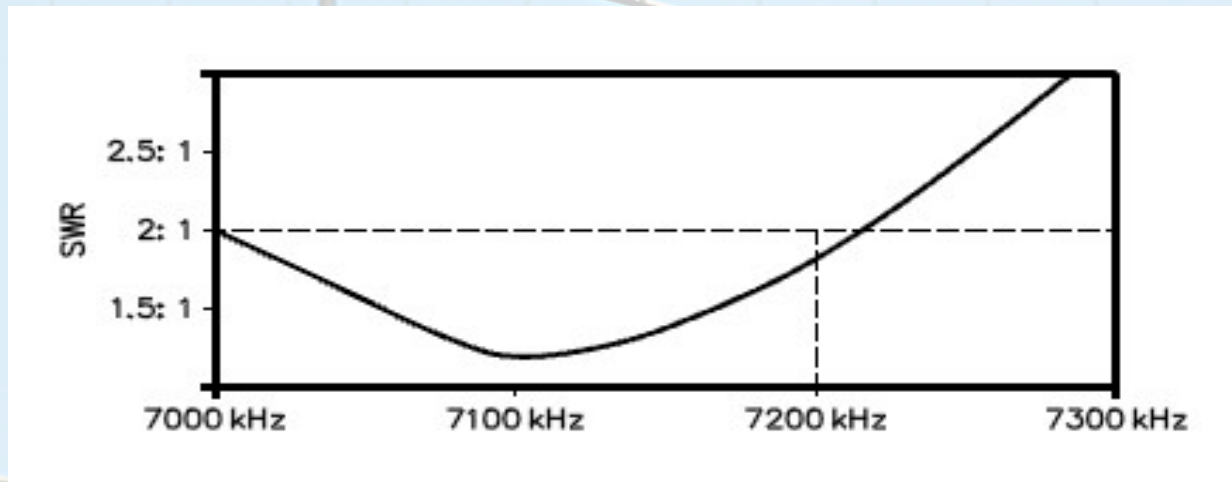
Resonance

The antenna system impedance equals $R_r + R_o + j2\pi fL - j/(2\pi fC)$ [r = radiation resistance]



The lowest point in the graph is the ***resonant frequency*** of the antenna system, at which inductive and capacitive reactances cancel, meaning $2\pi fL = 1/(2\pi fC)$

Antenna reactances



At the frequencies to the left of resonance, the antenna is a bit too capacitive (**too short**) and at those to the right of resonance, it's a bit too inductive (**too long**)

So, if you want to move its resonant frequency higher, for example, you'll need to ***shorten your antenna***

Fold-back

Once a transceiver detects that the reflected voltage reaches a specific threshold, it will start reducing its output power, to protect from overload, by using an internal ***fold-back*** circuit

So, in a sense, it monitors SWR to detect when to reduce its output power, but it's trying to protect against overload due to excessively ***low impedance*** or excessively ***high impedance***, not the reflected power

Consequence of fold-back

- So, when you're transmitting, and it seems like nobody's hearing you, check your power output (P_o) meter, which should display maximum on CW or FM or AM
- If your rig's meter doesn't show maximum, it's possible that your transceiver could be in fold-back due to high SWR
- Either check your SWR with an

Damage to your finals

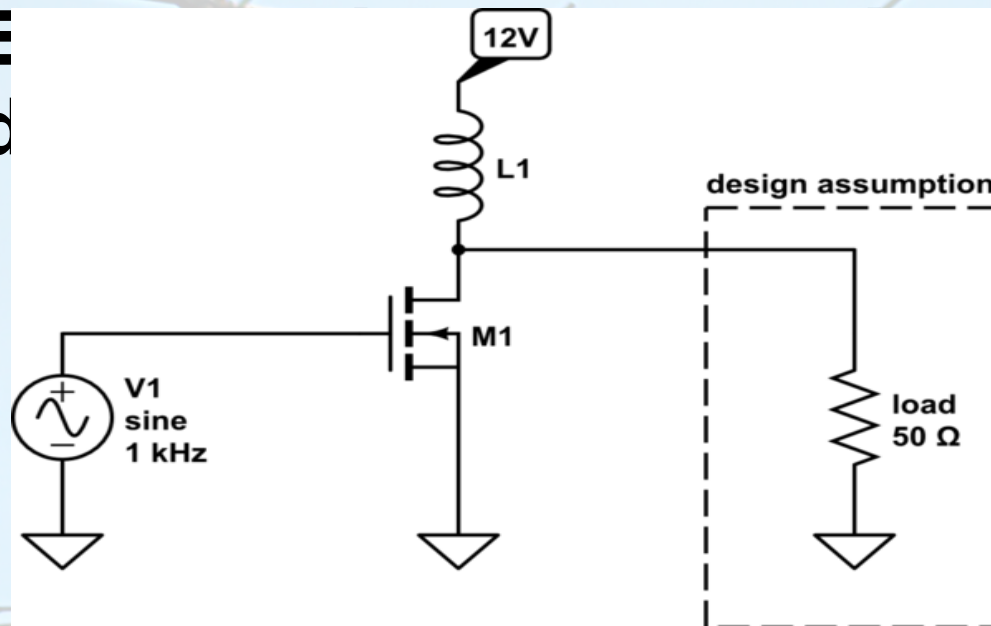
Wait...so, will a high SWR damage your finals?

Yes, it can, but *the damage is not caused by the reflected power coming back to your transceiver*

In the low-impedance case of high SWR, the extra-low impedance will cause the power transistor to draw excessive current, overheating the little guy, allowing the green smoke to escape

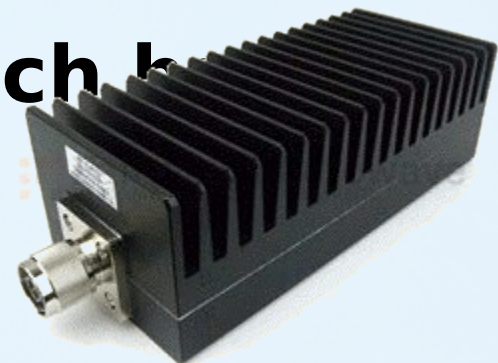
High-impedance case

In the high-impedance case of high SWR, the voltage of the pullup inductor rises because there's nowhere for the current to flow, and the resulting high V_{DS} will cause the MOSFET to break down.



How to get your SWR down

- **Get your antenna up higher**
- **Reconstruct or redesign your antenna**
- **Use a tuner**
- **Use another kind of matching device**
- **Use a dummy load (which has perfect 1.0:1 SWR!)**
- **Risk your life anyway**

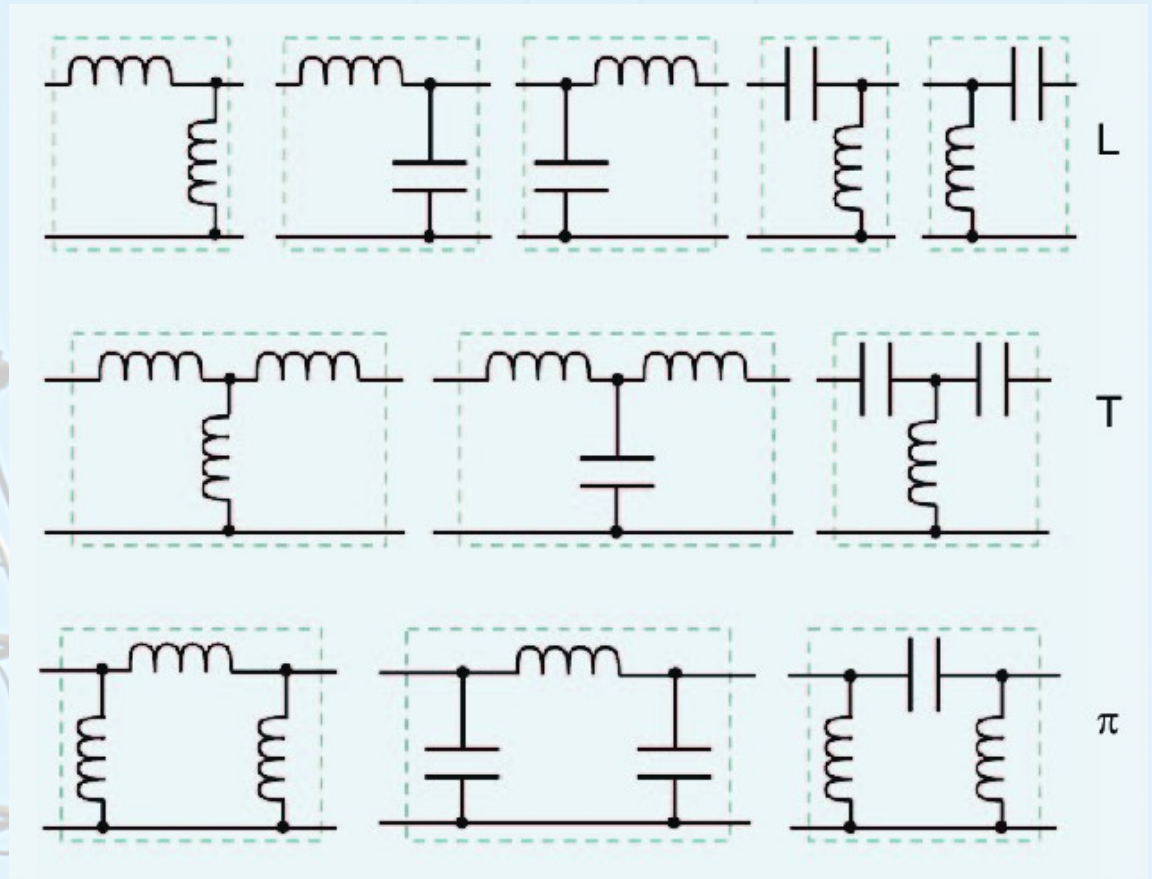


Using a tuner

- **A tuner is aptly named, because it tunes your antenna system for optimal operation**
- **Some hams claim that a tuner only "makes your radio happy"**
- **Kind of like saying a power supply only "makes my radio happy" because my rig enjoys being fed with 12 volts DC, but gets very angry when I attempt to feed it with 120 volts AC** □
- **But honestly, most rigs I've encountered are quite emotionless**

Using another matching device

- **Pi-match**
- **Pi-L match**
- **T-match**



Famous last words

- **If your highest SWR across the band is 1.9, leave your antenna where it is**
- **A low SWR says nothing about performance or efficiency (does not guarantee a good antenna or a good signal)**
- **For HF, I recommend using a rig that contains an internal tuner or purchasing an external tuner**
- **If you're new to HF, I recommend getting an automatic tuner**

Q & A

- **When's Noji birthday?**
- **What does he want for Christmas?**